PB86-100989

Investigation of Transient Aspects of Atmospheric Dispersion Processes in the Wake of a Building Through Video Image Analysis

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Sep 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-100989

EPA/600/D-85/217
September 1985

AN INVESTIGATION OF TRANSIENT ASPECTS OF ATMOSPHERIC DISPERSION PROCESSES IN THE WAKE OF A BUILDING THROUGH VIDEO IMAGE ANALYSIS

by

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*On Assignment from National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/D-85/217	2.
3. RECIPIENT'S ACCESSION NO. PB86 100989/AS	
4. TITLE AND SUBTITLE AN INVESTIGATION OF TRANSIENT ASPECTS OF ATMOSPHERIC DISPERSION PROCESSES IN THE WAKE OF A BUILDING THROUGH VIDEO IMAGE ANALYSIS	5. REPORT DATE September 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) A. H. Huber and S.P.S. Arya	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Same as 12.	10. PROGRAM ELEMENT NO. CDTA1D/09-2056 (FY-85)
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Atmospheric Sciences Research Laboratory - RTP,NC Office of Research and Development U. S. Environmental Protection Agency Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES
Extended abstract for American Meteorological Society Seventh Symposium on Turbulence and Diffusion, Boulder, CO. Nov 12-15, 1985

16. ABSTRACT

The processing of continuous video images is now very feasible and applicable to the study of the transient nature of atmospheric transport and the highly variable pollutant concentrations near buildings. Research is now ongoing to best develop and refine appropriate methods of analysis. The present capabilities for video image analysis are summarized.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 7
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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1. INTRODUCTION

Investigations of the atmospheric dispersion of hazardous air pollution are greatly complicated by the transient nature of atmospheric processes. Traditionally, concentrations of the air pollutant and meteorological measurements are sampled at several fixed points over the region and time period of interest. These data in conjunction with available mathematical models are used to infer the overall pattern of pollutant concentrations in risk assessments. These limited measurements do not always provide the necessary information which is needed to adequately understand all the important atmospheric processes — especially near buildings, mountainous terrain and/or for situations with chemically reacting pollutants. The time and spatial scales that are important to atmospheric dispersion can be better defined by analyzing a full picture of atmospheric transport. Photographic pictures of smoke have been used in research studies to provide a visualization of the pattern of atmospheric transport. Photographs have been limited to a few images over the time period of interest. The image has often been complicated by the unresolvable effects from nonuniform lighting and parallax. Recent exploratory studies at the U.S. EPA Meteorology Division's Fluid Modeling Facility have demonstrated the feasibility of using new video analysis processors for studying transient flows.

A research study of the transient nature of atmospheric transport and the highly variable pollutant concentrations near buildings is now ongoing in the U.S. EPA Fluid Modeling Facility's environmental wind tunnel. The study is designed to examine the near-wake flow immediately downstream of several block-shaped model buildings and to determine how this highly turbulent near-wake flow affects the dispersion of pollutants released near the buildings. Results from the study should provide a better understanding of the dispersion of pollutants from such full-scale sources as roof-mounted vents, short stacks, and accidental releases.

Point samples of pollutant concentration, velocity and turbulence data, and video images of smoke are being acquired. Information from the traditional point samples are not only being supplemented by video image data, but are also being compared to the video image data to provide information on the transient nature of the concentration field. By systematically varying flow parameters in the controlled environment of the wind tunnel, the relation between the transient characteristics of the dispersion process as determined from analysis of the video images can be evaluated against steady-state measurements from conventional instrumentation.

The processing of continuous video images is now quite feasible. Video images are recordable at the rate of 30 per second using standard equipment. This short time frame is adequate for the study of the most important atmospheric dispersion processes. Our present capabilities for video image analysis are summarized here. Work is ongoing to fully evaluate and refine these techniques.

2. TECHNIQUES

An oil fog smoke is generated and forced through a pipe appropriately placed in the wind tunnel to simulate a point source emission. High intensity arc lamps are appropriately placed downstream from the source to provide proper uniform illumination of the smoke. For the studies discussed here (1) the camera was mounted outside the wind tunnel overlooking a ceiling window, (2) a 200 mm high by 200 mm deep by 400 mm wide (i.e., cross stream) building was set along the middle of the tunnel floor, and (3) the smoke was emitted at floor level at the center at the leeward edge of the building. The results for two building orientations are discussed here. The building width is orientated either at 0 degrees (i.e., cross stream) or turned 45 degrees to the flow. The freestream wind speed was fixed at 2.5 m/s.

A black and white, low-light, video camera is used to sense the image which is recorded on a standard 1/2 inch videotape recorder. The image processing is done at the Image Processing Laboratory at North Carolina State University. The video signal from tape playback is fed into a video sequence processor which digitizes the pictures at the real-time ratio of 30 pictures per second and with a resolution of 512 x 512 pixels. Usually, some smaller part of the full picture is selected for processing (i.e., a cross-stream slice) in order to produce a manageable data set. The digitized picture matrix is then transferred and stored for later analyses. The picture is digitized based on a unitless gray scale from 0 to 255, which is fixed during each run based on its particular signal strength. The processor assigns a value near 255 to the brightest pixels and a value near 0 to the darkest.

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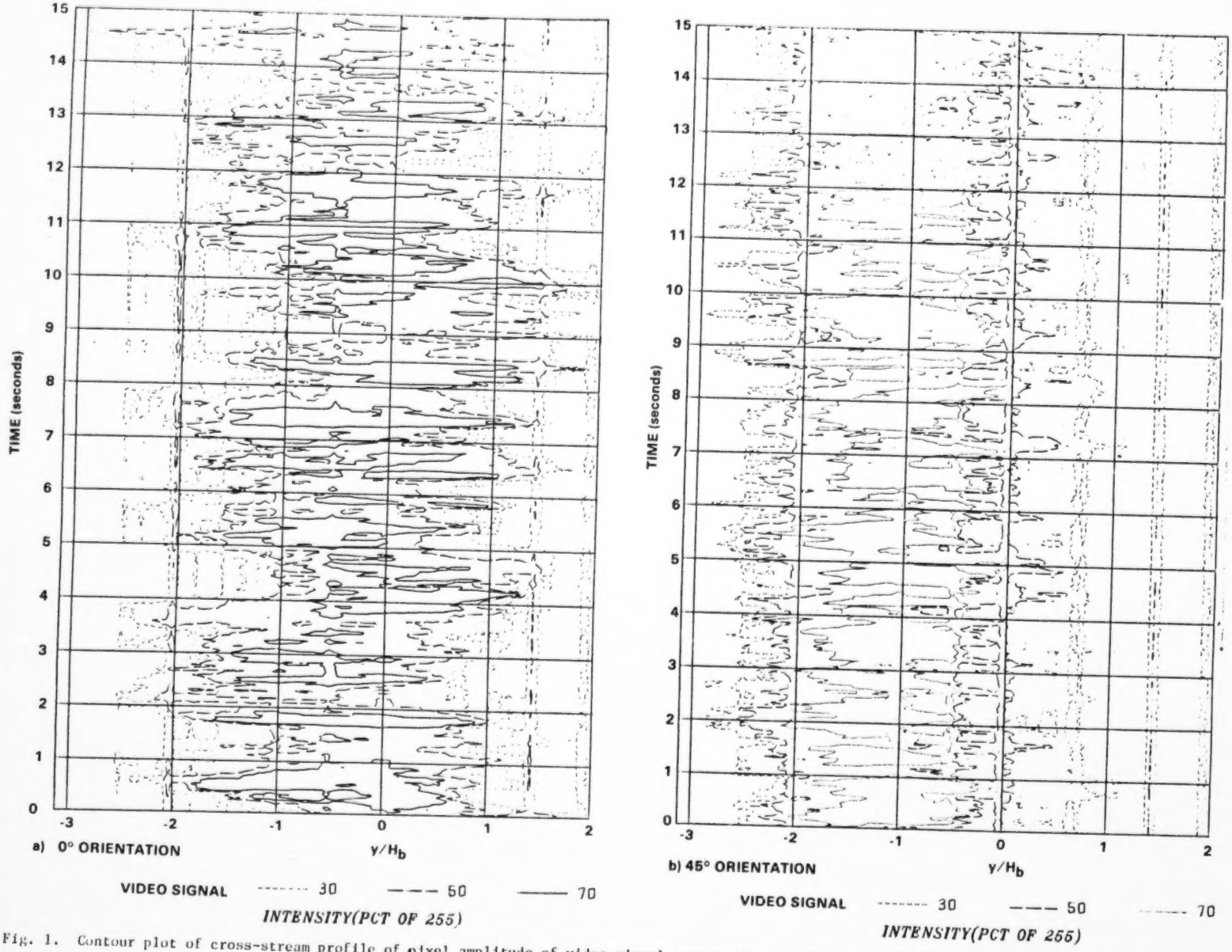

Fig. 1. Contour plot of cross-stream profile of pixel amplitude of video signal versus time, at $3H_b$ downwind of source building.

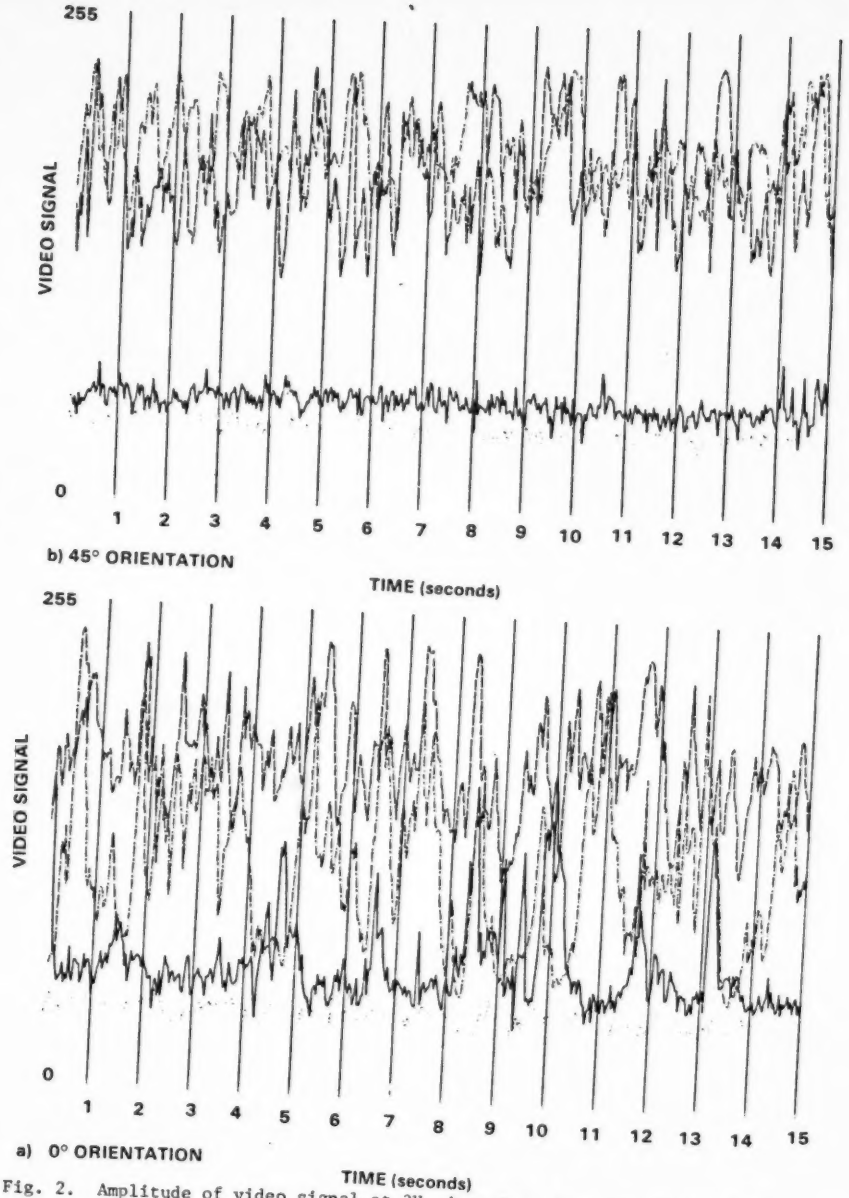
255
VIDEO SIGNAL
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
b) 45° ORIENTATION
TIME (seconds)
255
VIDEO SIGNAL
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
a) 0° ORIENTATION
TIME (seconds)

Fig. 2. Amplitude of video signal at $3H_b$ downwind of source building for cross-stream pixels at: y/H_b = -3 ----; -1.5 —·—·—; -0.5 — — —; 1.5 ——— ;

The linearity of the gray scales between the extremes has not yet been evaluated.

3. CONTOUR PLOT

A contour plot of cross-stream profile of pixel amplitude of video signal versus time can very efficiently show the temporal-spatial scales of the dispersion processes. Figure 1 presents such an analysis for cross-stream profiles taken at 3 building heights (H_b) downstream from the source. This position is near the downstream edge of the recirculating flow region behind the building and thus is a good position to observe the initial overall effect of the building on the dispersion pattern. The contours in Figure 1 outline the regions of smoke gray scale associated with the particular intensity as a percentage of the maximum possible amplitude (i.e., 255). The temporal oscillation of the flow is quite clear. The dispersing smoke oscillates and then sheds from side to side with intervening periods of buildup. While the presentation by Figure 1 contains too much information to fully comprehend, it does demonstrate the apparent real detail of the dispersion processes. Differences between the two orientations are noticeable — particularly

TABLE 1. Spectral Analysis

y/H_b	Sample Size	Signal Mean	Std. Dev.	Max.	Min.	Spectrum nS(n)	Frequency, n Cycles/Sec.
0° Orientation							
-0.5	450	178	26	241	117	1210	~1
-0.5	1800	189	27	255	114	1500	~1-1.5
-1.0	450	156	37	243	71	2350	~1
-1.5	450	120	40	242	54	2550	~1
-1.5	1800	136	34	255	72	2000	~1
-3.0	450	43	4	58	33	33	~13
						23	~1
45° Orientation							
-0.5	450	176	29	239	119	1650	~1.5
-1.0	450	196	24	239	114	1350	~1.5
-1.5	450	190	20	235	139	600	~1-2
-3.0	450	41	4	58	31	17-23	1-15

the plume's peak is narrower. The smoke was observed to favor one side simply because the source was slightly off center.

4. VIDEO SIGNALS

Figure 2 presents a run in time taken from several of the pixels positioned along the cross-stream profile represented by Figure 1. These signals can be studies to determine the structure of the dispersion processes. Research is underway to develop structure functions. Table 1 presents the most significant spectral components for selected individual signals. The characteristic frequency in the wake of the building is clearly 1 and 1.5 cycles/sec for the 0 and 45-degree orientations, respectively. Far from the building centerline (i.e., y/H_b=-3) the spectral components are more evenly spread over all frequencies such as for white noise.

5. COMPARISON TO POLLUTANT CONCENTRATIONS

The digitized pixel signals are clearly usable to study the whereabouts of smoke; however, there is uncertainty in the relationship between the unitless video signal amplitude to passive pollutant concentrations. Little is yet known about the gray scale function being used and at the consistency of the smoke source. The cross-stream video signals represented in the previous figures were normalized by the highest value for the profile. This was done after a value of 30 was subtracted from all signals, which is considered the background noise level. The smoke image represents vertical integrated concentration. Since the vertical concentrations are fairly uniform in the well-mixed region downwind of a building, the cross-stream profile should be representative of normal lateral dispersion. For example, in Figure 3, a 15-second mean video image profile (same data as for Fig. 1 and Fig. 2) is compared to actual normalized surface 2 min mean concentration for a similarly released hydrocarbon (HC) tracer. The comparisons are remarkably similar. This is very encouraging and suggests the possibility of being able to use these smoke signals to infer meaningful short-term concentration fluctuations.

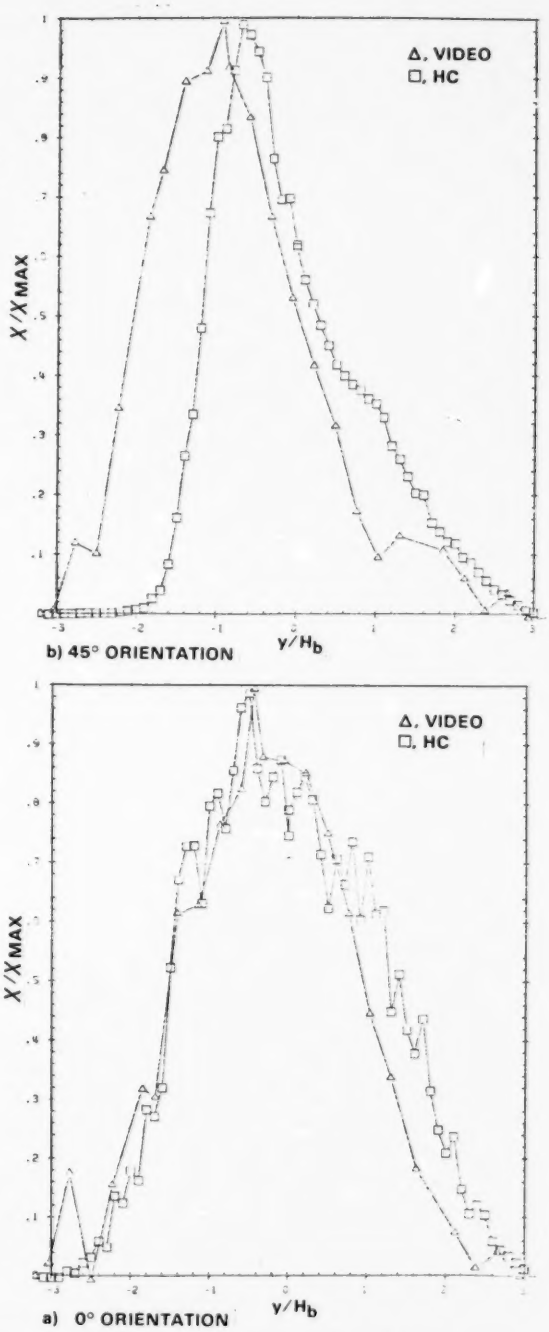

Fig. 3. Nondimensional comparisons of mean cross-stream profiles of video signal amplitude to HC concentrations at $3H_b$ downwind of source and building.

Acknowledgement

We greatly appreciate the guidance and assistance on the use of the video sequence processor provided by Dr. Sarah Rajala and Mr. Adnan Alattar, Department of Electrical and Computer Engineering, N.C. State University. Support for this work is provided in part through a Cooperative Agreement, CR-807854, between the N.C. State University and the U.S. Environmental Protection Agency.